Stress Gradient in Solid Methane at High Pressures

Abstract. *The magnitude of the axial pressure gradient at 77°K (11 percent per centimeter) in solid methane compressed along one axis for applied pressures up to 10 kilobars was determined by comparing the electrical resistance of a pair of doped tellurium pressure gages with that of a set of single-crystal gages made of high-purity bismuth. The existence of the pressure gradient revealed the causes of deformation in metal tensile specimens embedded in solid methane and cycled to high pressure.*

Solidified gases such as Ar, CH_4, and Kr are often used as the pressure-transmitting media in cryogenic experiments at high pressures. The shear strength of these solids is small (*1*) compared to the maximum pressures applied, and the stress in uniaxial compression has been assumed to be nearly hydrostatic (*2*). Resistance measurements up to 10 kb on a pair of sintered Te gages (99.999 percent) doped with Bi (*3*) and on a pair of single-crystal Bi gages (99.999 percent), embedded 25 mm apart in solid CH_4, indicate pressure gradients sufficient in magnitude for the medium to be considered nonhydrostatic. These data substantiate the observation that tensile bars of metal alloys are severely deformed when embedded in solidified CH_4 and cycled to pressures up to 14 kb (*4*). All high-pressure experiments reported were carried out in a piston-in-cylinder apparatus designed for use at cryogenic temperatures (*5*); the apparatus may also be used near room temperature.

The Te gages (1.5 mm long and 1.5 mm in diameter) were mounted on a removable terminal plug at one end of the pressure chamber (67 mm long and 7.5 mm in diameter). The gages were axially located in the pressure chamber 16 mm and 41 mm from the terminal plug, respectively. Resistance measurements were made with a potentiometer. Each gage was fabricated from the same lot of material so that the variation of the resistance ratio with pressure would be identical. To verify this, the two Te gages were cycled several times to 10 kb in a hydrostatic medium (hydraulic oil) at 273°K. The resistance ratios for the gages agreed to within a few percent. We therefore concluded that the behavior of the gages would be nearly the same in any hydrostatic or quasi-hydrostatic environment, although the specific behavior would depend on the temperature.

At 77°K the two Te gages were embedded 25 mm apart in solid methane, and the applied pressure was raised to 10 kb. At maximum pressure the total length of the chamber was reduced to approximately 50 mm as the piston advanced under loading. The transmitting pressure was determined from a hysteresis curve in which piston displacement was plotted as a function of applied pressure. This method (*6*) allows one to correct for press friction as well as friction between the piston seal and chamber wall. The resistance data (Fig. 1) for increasing pressure indicates an axial pressure gradient of 11 percent per centimeter for applied pressures from 5 to 10 kb. This gradient calculation was determined from the pressure differentials (Fig. 1), and it is assumed that the separation of the Te gages is constant to a first approximation.

Since the experimental arrangement was not suitable for strict hydrostatic measurements at 77°K, that is, with a liquid or gas pressure-transmitter, a set of single-crystal gages made of high-purity Bi was subjected to the same cycle of pressure under similar gage placement. The same experimental conditions were maintained during the condensation of the CH_4 and in the subsequent resistance measurements (Fig. 1). Although the pressure sensitivities of Te and Bi are different and the pressure dependence of the materials is opposite, the pressure gradient is the same within experimental error. It is, therefore, unlikely that the observed gradient is due to differences in gage sensitivity.

The presence of a stress gradient in CH_4 (*7*) was substantiated by an experiment in which tensile bars 25 mm long supported by a steel pin 13 mm long were mounted on the terminal plug in such a way that the ends of the specimens corresponded to the approximate positions of the Te and Bi gages described above. The same high-pressure apparatus, condensation procedures, and approximately the same pressure-time cycle were used. Pressure cycles to 15 kb on Cu and Al resulted in gross deformation of the specimens. At no time did the specimens contact the advancing piston. However, the specimens had been forced downward about 6 mm, which bent the supporting pin. Such a downward movement could not have occurred if the medium had hydrostatically transmitted the applied pressure. To avoid bending and permanently deforming the specimens, limiting pressures of 4.5 and 9.0 kb were necessary for Al and Cu, respectively. Using the Te and Bi experiments as a basis and assuming a linear pressure gradient along the chamber length (50 mm) at maximum pressures of 4.5 and 9.0 kb, we calculated a pressure differential across the tensile bars that corresponds within 15 percent to the low-temperature yield strength of the

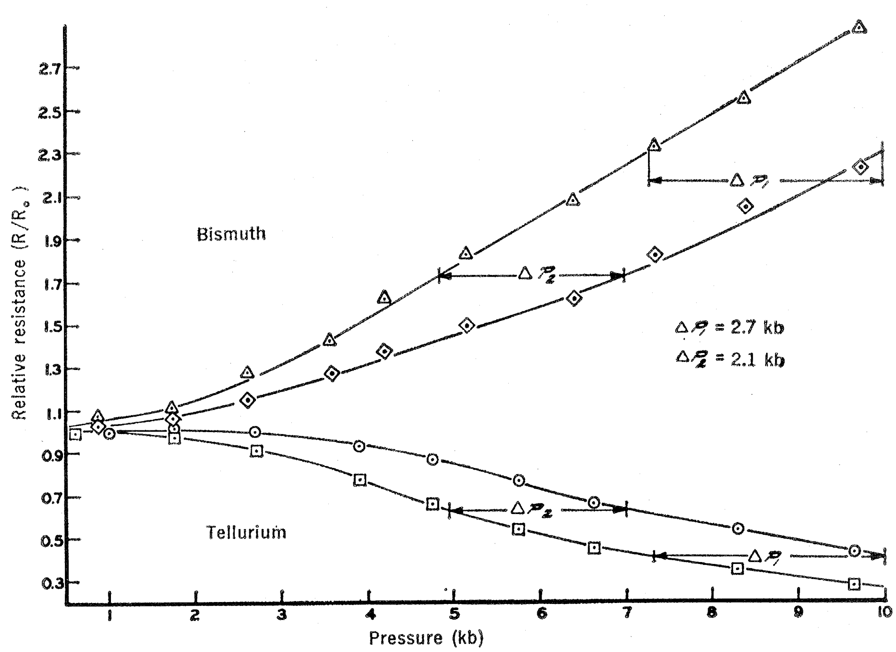

Fig. 1. Relative resistance plotted as a function of increasing pressure for axially located gages (25 mm separation) at 77°K in solidified CH_4; □ represents the Te gage located 41 mm from the terminal plug; ○ represents the Te gage located 16 mm from the terminal plug; △ represents the Bi gage located 41 mm from the terminal plug; ◇ represents the Bi gage located 16 mm from the terminal plug.

respective metals (8). Tensile bars made of steel, Be-Cu, and stainless steel with considerably higher yield strengths remained undeformed after pressure cycles to 14 kb.

It is not possible, with the available data, to give a complete explanation of the origin of the stress field. However, the shear strength of the solidified gas (9) at this temperature and these pressures is certainly of significance in any detailed analysis.

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References and Notes

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10. We thank C. S. Goldsworthy and R. Vanark for their assistance in the high-pressure experiments.

23 August 1968

Radar Observations of Icarus

Abstract. *Radar observations of Icarus were made in mid-June 1968, at the time of closest approach. From the data, it is estimated that the radius is between 0.3 and 0.6 kilometer and the rotation period between 1.5 and 3.3 hours. A set of round-trip Doppler shift measurements is given.*

Advantage has been taken of the recent, and rare, close approach of the asteroid Icarus to observe it by means of radar. Measurements of the radio frequency spectrum of the echoes were made. They provide data dependent upon the size, shape, spin, velocity, and radar cross section of the target.

The orbit of Icarus is such that it comes within 4 million miles of Earth only once in 19 years, and the last occurrence, on 14 June 1968, was the first opportunity for radar study. Icarus is an extremely difficult radar target; its radar detectability is only 10^{-3} times that of Mercury (at closest approach) and 10^{-12} that of Moon. Only the most powerful and sensitive radars of modern technology can detect this asteroid.

The measurements to be described were performed at the Jet Propulsion Laboratory's Goldstone Tracking Station. A newly developed 450 kw transmitter had just been installed on an 85-foot (26-m) dish antenna. The receiver was connected to a 210-foot antenna, approximately 14 miles (23 km) away from the transmitter. Because of this separation, it was possible to transmit and receive simultaneously most of the time. However, when the elevation angle was low or during the several hours of closest approach when the Doppler went through zero, it was necessary to transmit and receive in alternate cycles. Each cycle lasted 43 seconds, the round-trip time of flight.

The radar station parameters were as follows:

Power	450 kw
Frequency	2388 Mhz
Two-way antenna gain	116.0 db
System temperature	21°K

Pure monochromatic waves were beamed at Icarus. The frequency spectrum of the weak echoes was measured at the receiver. Any rotation that Icarus might have would broaden the spectrum of the echo and leave a characteristic signature upon it. Three functions of the radar were controlled by ephemerides: pointing of each of the two antennas and tuning of the receiver to account for the relative velocities of Icarus and the radar station.

Ordinarily, receiver runs of 30 minutes were made, and the resulting spectrum was displayed. Because of the unusually low power level of the echo, none of these runs produced a clear detection of Icarus. Although there were indications of an echo, they were obscured by the random fluctuations of the spectra. When 4 hours of data were averaged, however, the result was not only positive detection of Icarus, but also an indication of power bandwidth and center frequency. Altogether, seven such average spectra were taken. They are reproduced in Fig. 1. Each is the result of 3 to 4 hours of averaging.

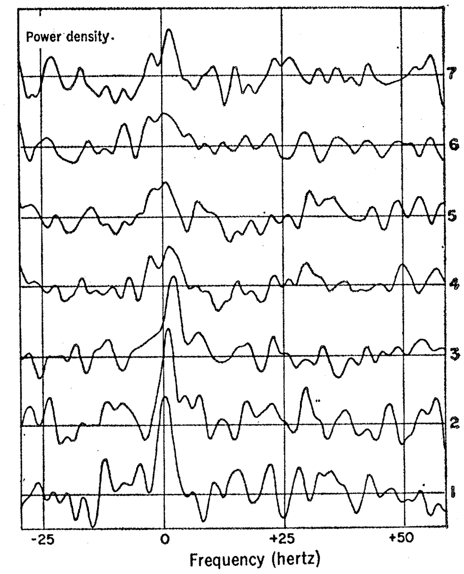

Fig. 1. Individual spectra of the Icarus echo. The averaging time was 3 to 4 hours each.

The radar was calibrated by directing it at the planet Mercury. Everything was unchanged except for the three ephemerides. Figure 2 is a sample result of averaging 9 minutes of echoes from Mercury. Note the different scales in frequency of the two figures.

The total received power is obtained from the area under each spectrum. An average echo power of 0.63×10^{-22} watts was obtained for Icarus. When the radar parameters of range, antenna gain, and so forth are taken into account, the result is the radar cross

Table 1. Values of radius and period derived from the spectrograms, assuming various reflection models for Icarus.

Type	Radius (km)	Period (hr)
Mercury	0.6	0.7
Venus	.5	.5
Moon	.7	.9
Rough, metallic	.3	1.5
Rough, stony	.6	3.3

Table 2. Measured values of Doppler shift along with the corresponding time for each spectrogram.

Spectrum	Received time (U.T.)	Doppler (hertz)
1	14 June 1968, 0530	+115,417.1±0.3
2	14 June 1968, 2220	−10,324.1
3	15 June 1968, 0430	−61,207.2
4	15 June 1968, 0940	−104,441.9
5	16 June 1968, 0140	−202,453.5
6	16 June 1968, 0630	−234,710.0
7	16 June 1968, 1000	−255,404.7